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Research Article

Study of Five Joint Slope Angels on Bending Strength of Poplar Wood (*populus alba* l.) Finger Joint Connection

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Abstract

In this research, the effect of five different slope angels of the joint on bending strength of poplar (Populus alba L.) finger joint connection, bonded with polyvinyl adhesive, was studied. Modulus of rupture (MOR) and Modulus of elasticity (MOE) of joint perpendicular with strips edges, 15°, 20°, 25° and 30° slope joints, referring to the first one direction, were measured, according to norms ISO 3133 and 3349.120 samples in total, 24 samples for each type of joints, with dimensions 20x20x320 mm, were conditioned and tested by means of mechanical testing machine, in the Faculty of Forestry Sciences of Tirana. The MOR of perpendicular and 15° slope joints resulted almost the same, 36.75 N/mm^2, while of 20° and 25° slope joints resulted 7% and 24% higher, respectively 39.16 and 45.66 N/mm^2. With regard to the angel 30°, MOR value resulted 10% higher comparing to the straight connection, 40.33 N/mm^2. Beyond the angel 25° modulus of rupture began to decrease. Modulus of elasticity wasn't affected in a distinct manner by the slope angle of connection. For perpendicular joint it was 10152.12 N/mm^2, while for 15°, 20°, 25° and 30° slope joints resulted 9944.91, 14484.8, 17697.59 and 10155.98 N/mm^2 respectively. The research results obtained were discussed in order to analyze and evaluate the slope angle of finger jointing, which could affect its utilization potentials.

Key words: *finger joint, poplar, bending strength.*

Introduction

Wood, as one of the best construction materials of the world, presents nearly unlimited applications. It has an attractive appearance and a long lifespan, it handles with easy and its strength/weight ratio is high. No other construction material is as much ecological as wood. By the other hand wood presents some disadvantages, too. It is highly anisotropic material, its properties vary within a wide range and it is known to be sensitive to exposure to moisture.

To avoid some of the disadvantages of solid wood, satisfying so the demand of construction industry for high-quality dry timber construction materials with more consistent and reliable properties, several engineered wood based materials have been developed over the years. Such materials are more homogeneous than solid wood and their properties do not vary as much as in solid wood.

The most well-known from these materials is glued laminated timber (glulam). It is usually manufactured to order for architectural applications. It consists of two or more layers of lumber, called laminations, glued together, and can be produced as long as can be transported, due to finger joint connections, which are decisive elements of its strength.

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Finger-joined lumber is now widely used in structural products such as glued-laminated timber, I-joists, wall studs and trusses, because of its desirable properties such as straightness, dimensional stability, interchangeability with un-jointed lumber and unlimited length.

The strength of finger-joint determines considerably the strength of glulam and depends on some parameters which always must be taken into account, like finger geometry, assembly pressure, curing time, adhesive type, wood density and moisture content as well as pre-treatment of wood.

Finger-joint geometry is one of the most important variables determining joint strength (Selbo, M.L *et al*. 1963; Fisette, P.R *et al*, 1988; Colling, F *et al*, 1992). For broadleaves of low to medium density destined for structural products, the optimal finger's length appears to be 18 mm (Ayarkwa, J *et al*, 2000), while the slope 1 in 16 to 1 in 20 produces elevate joint strength comparable to clear wood strength when is properly bonded (Strickler, M.D *et al*, 1980). Between pitch and tip width, the last one results as a geometrical parameter of great importance in strength of finger-joint. Smaller to be the tip width, stronger is the finger-joint. The recommended tip width is from 0.5 to 0.7 mm (Hernandez, R *et al*, 1988). If fingers length becomes larger without increasing fingers pitch, the strength of connection increases, but the best results are obtained for values of length/pitch from 4 to 5 (Selbo, M.L *et al*, 1963). Gaps between fingers tips and bases appear as necessity for accumulation of excessive adhesive. According to the German Standard 68140-1, this gap varies in 0.03 of finger's length (DIN 68140, 1988). Anyway, modulus of elasticity (MOE) is not significantly influenced by finger's profile geometry (Ayarkwa, J. *et al*, 1999).

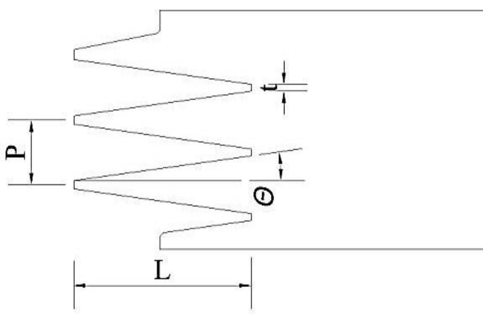
To guarantee a good performance, a finger-joint must be subjected to a proper end pressure, curing time and adhesive application. The German standard DIN 68140-1 mentioned above clearly shows that assembly pressure have to become short of if the finger's length increases (DIN 68140, 1988). The end pressure can be low if fingers are well fitted, saving in this way the energy (Jokerst, R.W *et al*, 1981). The finger-joint has the best performance at a precise end pressure, according to wood species. Lower or higher end pressure can result in lower tensile strength (Bustos, C *et al*, 2002; Madsen, B *et al*, 1962).

Generally, there are two types of adhesives used for finger-joined connections, polyvinyl acetate (PVA) and resorcinol adhesives (RF), as well as other combinations based on both of them. The first one is limited to non structural and interior applications, while the second one is used for structural and exterior/interior load-bearing applications. Anyway, different studies have shown that other types of adhesives produce an acceptable performance, comparable to RF adhesives (Vrazel, M *et al*, 2003).

Many studies have showed that wood species with density higher than 700 kg/m^3 give uncertain performance, while those with lower density appear to be more predictable in their performance (Lamb-Shine *et al*, 1982).

In this research, the effect of five different slope angels of the joint on bending strength of poplar (*Populus alba* L.) finger joint connection, bonded with polyvinyl adhesive, is studied. It aims to give information about opportunities for production and application of a better quality and performance of wooden products and their structures. The selection of wood species is conditioned by the growing interest in poplar, taking into account that this wood presents good opportunities for glulam application, because of its low cost and weight (Castro, G *et al*, 1993).

Materials and method



Pitch *P* = 6 mm, length *L* = 5 mm, width of fingertips *t* = 1 mm and slope angle *Θ* = 22°.

Figure 1 Geometric profile of fingers

The study was based on comparative laboratory method, cause-consequence (Creswell, W.J., 2003). The method consisted to quantity evaluation of a specific phenomenon caused by a provocative factor and after that, the evaluation of the same phenomenon in the situation of the factor's absence. In our case, the phenomenon was the static bending strength of finger-joint connection, and the provocative factor was the slope of joint (slope of fingers). Wood material for production of samples was selected from pieces of kiln dried poplar boards. From selected pieces were sawn blocks without deformations or structure defects with dimensions of cross-section 5×6 cm, and various lengths. Fingers profiles were produced on one head of each block by means of a spindle moulder with sliding table. The geometric profile of cutterheads (knifes), which means the geometric profile of fingers is shown in Figure 1.

There were produced five series of fingers, perpendicular with blocks edges (straight fingers), as well as 15°, 20°, 25° and 30° slope fingers, referring to the first one direction ($\beta_1 = 75°$, $\beta_2 = 70°$ $\beta_3 = 65°$ and $\beta_4 = 60°$). In Figures 2 and 3 are shown the two types of produced samples.

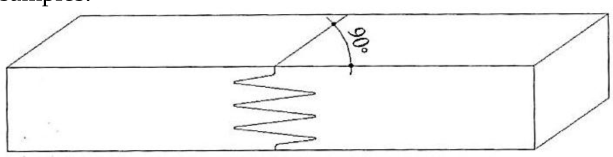


Figure 2 Finger-joint with straight fingers

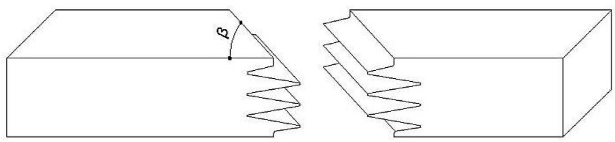


Figure 3 Finger-joint with slope fingers

Following fingers production and combination of blocks two by two, a PVA glue (Neon, ALBANIA) was applied on one profiled head by brush. Then, the blocks couples were pressured manually by means of hand grip vices for a period of 24 hours. After, the jointed blocks were cut and planed to final dimensions 20×20×320 mm, to produce bending strength samples according to the standard ISO 3133 and ISO 3149 (ISO 3133, 1975; ISO 3149, 1975).

The samples were conditioned to reach equilibrium moisture content around to 12%, and were tested by means of mechanical testing machine (Controlab, FRANCE). Modulus of rupture (MOR) and Modulus of elasticity (MOE) of joint perpendicular with strips edges, as well as 15°, 20°, 25° and 30° slope joints, referring to the first one direction, were calculated in N/mm^2 according to standards ISO 3133 and ISO 3349 as follows:

$$MOR = \frac{3P_{max} \times l}{2bh^2} \quad (1)$$

$$MOE = \frac{l^3 \times \Delta P}{4bh^3 \times \Delta y} \quad (2)$$

where P_{max} was the breaking load in newtons (N), l was the distance between the centres of supports in millimetres (mm), b was the breadth of the test piece in (mm), h was the height of the test piece in (mm), ΔP was the difference between respective loads of two points selected on the linear section of load-deformation graphic in (N), and Δy was the relative increment of deflections in bending in (mm).

In total were tested 120 samples, 24 for each series of samples. After testing, the density of wood was measured according to the standard ISO 3131, using pieces provided by destroyed samples (ISO 3131, 1975).

Results and Discussions

Mean values of modulus of rupture (MOR) and modulus of elasticity (MOE), together with respective standard deviations, measured in static bending tests are shown in Table 1.

Table 1 Results of modulus of rupture (MOR) and modulus of elasticity (MOE)

Slope of connection (Slope of fingers)	MOR [N/mm^2]	Stand. Dev.	MOE [N/mm^2]	Stand. Dev.
90° (0°)	36.69	4.17	10152.12	1228.66
15°	36.75	4.06	9944.91	1173.83
20°	39.16	5.31	14484.8	1015.72
25°	45.66	7.32	17697.59	1455.36
30°	40.33	4.54	10155.99	1144.34

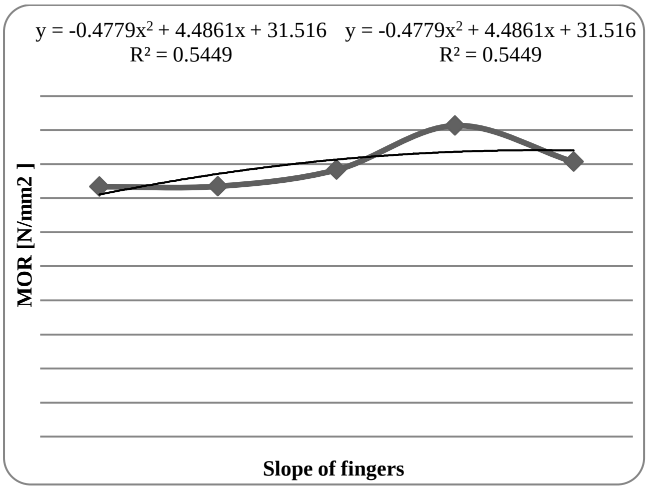


Figure 4 Modulus of rupture (MOR) as a function of the angle of fingers slope

Mean value of the density of poplar wood used in our study resulted 0.44 g/cm^3, with a standard deviation 0.042. The bending strength (MOR) of tested samples ranged from 36.69 N/mm^2 to 45.66 N/mm^2. On the first sight MOR values appeared to be lower comparing to those of other soft woods, but were in the same line with what had been found by other studies for the same wood species, taking into account the poplar density (Castro, G *et al*, 1997). From examination of results can be noted that bending strength was influenced by the slope of connection (slope of fingers). The MOR of straight and small angle slope finger-joints appeared to be comparable, with a little superiority of the last one, while the MOR of 20° and 25° slope joints resulted 7% and more than 20% higher comparing to both first angles. With regard to the angel 30°, MOR value resulted more than 10% less, comparing to predecessor one (Figure 4).

It can be explained taking into consideration that in fourth and fifth cases (25° and 30°), the contact surface between two components (blocks) glued together was higher, giving so a stronger resistance comparing with three first cases (90°(0°), 15° and 20°). For low angles the modulus of rupture was inconsiderable affected. Anyway, based on the total tests results, can be said that to receive a notable difference in bending strength, the slope angle of connection must to be no less than 25°.

From the other side modulus of elasticity (MOE) wasn't affected in a distinct manner by the slope angle of connection (Figure 5).

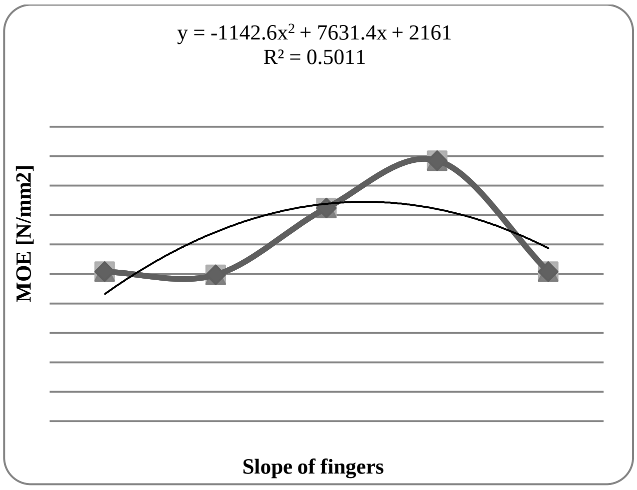


Figure 5 Modulus of elasticity (MOE) as a function of the angle of fingers slope

For perpendicular joint it was 10152.12 N/mm^2, while for 15° and 30° slope joints resulted 9944.91 and 10155.98 respectively, much lower than two other intermediate angels. It wasn't noted a correlation between MOE values and directions of connection, which would make possible to specify a well scientific supported conclusion.

Conclusions

Based on research results obtained during this comparison study we can say that the slope angle of finger jointing connections of poplar wood presents a better performance referring to mechanical features in static bending, giving so good opportunities for its utilisation. The slope angle 25° and 30° produce values of modulus of rupture 24% and 10% higher comparing to straight finger-joint connection. The maximum value of MOR is obtained for the angel 25°, beyond this angel modulus of rupture begins to decrease. By the other hand, modulus of elasticity is not affected by the fingers slope.

With regard to state of art of the technology by means of the finger-joint is produced, the production of slope fingers can be applied without added costs related to machineries processing or fingers profiling.

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